BARELY VISIBLE IMPACT DAMAGE DETECTION USING LAMB WAVE TECHNIQUE

[1,2] BURKOV M.V., [1]LYUBUTIN P.S., [1]BYAKOV A.V.
[1] Institute of strength physics and materials science, Akademicheskiy avenue 2/4, Tomsk, Russia
[2] Tomsk Polytechnic University, Lenin avenue 30, Tomsk, Russia
E-mail: burkovispms@mail.ru

The recent trend in non-destructive testing is a rapid development of structural health monitoring (SHM) concept based on the evaluation of various structural parameters using embedded sensor system. Signals registered by the system are sources of the structure health information: presence of damages, material degradation, etc. In order to design robust SHM systems sophisticated algorithms for data processing are to be developed. Aerospace industry is interested in the development of SHM systems however high demands on safety and strict weight limitations make this task even more complicated. Recent papers show the increasing interest to ultrasonic guided waves for SHM. These waves due to low attenuation can be used in the aerospace to monitor large areas like aircraft skins. Moreover new aircraft designs utilize wide application of CFRPs which are susceptible to impact damaging. Barely visible impact damages (BVID) itself do not threat the residual strength but can grow during operation thus they should be detected and repaired timely. This work deals with the investigation of functioning of Lamb wave technique for detection of BVIDs of honeycomb CFRP.

The material to be tested is a honeycomb panel with CFRP skins. Network consists of 4×4 PZTs transducers adhesively bonded to the surface of the panel. Each PZT can be used as generator or sensor thus there are 132 generator-sensor pairs obtained for the 4×4 network. Hanning window-modulated 5-cycle sine wave is used as a testing signal generated using AWG-4105 and captured by Handyscope HS4-5. In order to increase S/N ratio the signals were averaged by 100 times. The technique is based on the analysis of attenuation of ultrasonic waves due to emergence of impact damage. In order to assess the state of tested object one should compare registered ultrasonic signals for initial (baseline) and damaged states for each generator-sensor pair using following parameters: *dA* – difference of envelopes and *dP* – difference of Fourier spectrum energy.

Baseline and damaged states are compared in the software to calculate location and severity of damage. For each generator-sensor pair *dA* and *dP* are calculated and sorted in ascending order thus the pairs with the highest decrease of amplitude or energy are in the upper part of the list. Then *N* pairs (paths) are selected from the top of the list and used for damage location procedure. After the paths are chosen the intersection points are found. For each pair of paths there is no more than one intersection point having its weight equal to product of *dA* or *dP* of two paths producing this intersection. Damage location is calculated as mean of the obtained intersection points: $r = \Sigma\, r_i \cdot w_i / \Sigma\, w_i$, where r_i and w_i are coordinates and weight of *i*-th intersection point. Damage index $DI = \Sigma\, w_i, / n$, where n is a number of intersection points, describes the severity of the damage: the higher the index the more the damage is severe.

In present work there were 3 testing frequencies (50, 100 and 200 kHz) while signal processing technique utilized 10 or 20 calculation paths, thus there were 6 predicted coordinates of damage calculated for different conditions for each parameter (*dA* or *dP*). The proposed technique is quite simple but due to discrete positions of intersection points there can be large random error thus all 6 calculated points are averaged obtaining the resulting coordinate of damage location.

The experimental testing of the technique consists in detection of BVID of honeycomb panel obtained using drop-weight technique. There were 5 impacts with a step of 1 J (Table 2). The specimen is irreversibly damaged after impact thus each time the baseline state should be changed. During real operation such BVID is repaired with subsequent registering the ultrasonic signals for new baseline state. In this work the previous damaged state was used as baseline for next experiment, however the total amount of BVIDs will influence the results of damage location due to nonhomogeneous propagation of ultrasonic waves.

Totally 5 experimental tests were performed. Table 1 show the results of test BVID-3 after the impact with 3 J in the point X=251, Y=74. The data is following: X and Y are coordinates of predicted damage location; Δ – is a location error equal to distance between predicted location and impact point; DI – is a damage index.

Table 1 - Results of test BVID-3

Parameter	**X, mm**	**Y, mm**	**Δ, mm**	**DI**
dA	217.96	60.99	35.51	0.0085
dP	219.66	69.64	31.64	0.000054

The damage obtained with the energy 3 J can be classified as barely visible impact damage: the dent is quite small while the coating paint is unbroken but the honeycomb core is delaminated from the skin. The error of damage location is about 30-35 mm.

Table 2 - Results of experimental investigation

Test number	**Impact energy, J**	**Coordinates of impact**		**Location by dA**		**Location by dP**	
		X, mm	Y, mm	Δ, mm	DI	Δ, mm	DI
BVID-1	1	132	62	72.25	0.0039	102.28	0.000024
BVID-2	2	65	202	42.15	0.0076	79.40	0.000029
BVID-3	3	251	74	35.51	0.0085	31.64	0.000054
BVID-4	4	321	153	57.54	0.0096	33.39	0.000052
BVID-5	5	187	177	27.57	0.0243	10.05	0.000126

Table 2 show location errors and damage indexes for dA and dP parameters for tests from BVID-1 to BVID-5. Lamb waves have low attenuation and can be effectively used for monitoring of large areas but characterized by complex propagation mechanism that makes the analysis of signals for designing of SHM system complicated. However data processing consisting in evaluation of attenuation across entire PZT network (tomography principle) is quite simple but effective. Analyzing the results of performed research the following can be concluded:

- technique for damage detection using Lamb waves allows location of BVIDs with acceptable precision while damage index describes their severity. The mean error of detection the location of the impact damages is about 25-80 mm depending on the energy while damage index allow classifying the obtained BVIDs;
- results of damage detection are predicted location coordinate and damage index which should be analyzed jointly: low DI informs about low probability of damage in the predicted area when high DI is related to high probability of damage presence. More sophisticated technique of processing and representing of data are probability distributions reflecting the damage presence possibility throughout all investigated object;
- detailed analysis of the results allow making the conclusion about insufficient location accuracy near the borders of the network due to discrete method of damage location: the number of path intersection points near the mass center is much higher than on the periphery. The drawback can be partially solved by increasing the weight coefficients of these intersection points;
- the results of the research are good enough taking into account that on the initial stage of application of such SHM techniques they will be focused on the registering the event of emergence of impact damage since the detailed non-destructive testing will be performed using traditional well-established and precise methods (e.g. eddy current or ultrasonic).

Acknowledgements

This work was performed within the frame of the Fundamental Research Program of the State Academies of Sciences for 2013-2020, line of research III.23 and with a partial support of RF President Council Grant for the support of leading research schools NSh-5875.2018.8 and RF President grant SP-2167.2016.3.